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PHYSIOCHEMICAL/RHEOLOGICAL CONTROL OF NONMETALLIC MATERIALS.(U)
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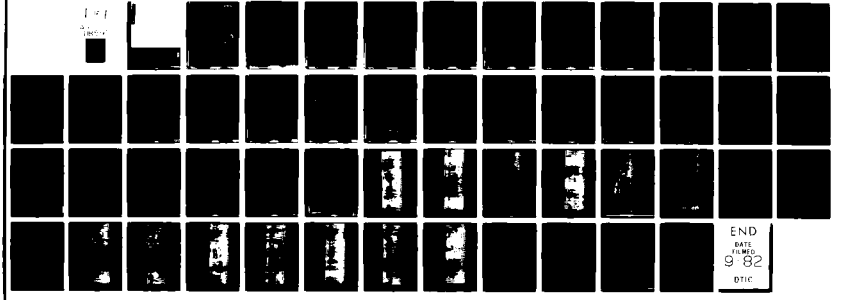

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A similar gas chromatographic technique was used to determine the percentages

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The objective of this program has been to evaluate the use of physiochemical and rheological methods to improve the quality control nonmetallic consumables used in the bonding and production of composites and also the quality control of foaming adhesives.

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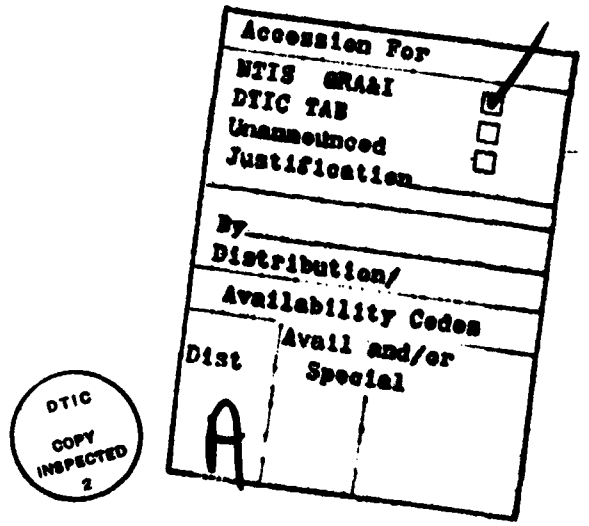
FORWARD

This final report covers work performed from 1 August 1981 to 1 August 1982 under Contract No. N00019-81-C-0119 by the Material and Process Development Department of the McDonnell Aircraft Company, McDonnell Douglas Corporation, St. Louis, Missouri. The program was administered under the direction of the Naval Air Systems Command by Messrs. Richard L. Dempsey and John Gurtowski.

The program was managed by Mr. R. J. Juergens, with Dr. J. F. Carpenter as Principal Investigator. Major contributors were Messrs. T. T. Bartels, L. F. Bunck, R. A. Haar, D. L. Scheer, G. T. Stillwell, J. E. Twichell, and C. E. Wilson and Ms. M. E. Smith of the McDonnell Materials Laboratory.

For the purpose of this report, certain resin components are identified by generic designations rather than by trade names or chemical names.



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LIST OF ABBREVIATIONS

RDS	Rheometrics Dynamics Spectrometer
IR	Infrared Spectroscopy
GC	Gas Chromatrography
MS	Mass Spectrometry
DSC	Differential Scanning Calorimetry
RT	Room Temperature
ET	Elevated Temperature
T_{gel}	Temperature at Gel
T_g	Glass Transition Temperature
η	Viscosity
t_{gel}	Time to Gel
G'	Storage Modulus
G"	Loss Modulus
ΔH	Enthalpy
ϕ	Linear Heating Rate
FTIR	Fourier Transform Infrared
TGA	Thermogravimetric Analysis

1.0 INTRODUCTION AND SUMMARY

Over the past 10 years, physiochemical and rheological test methods have been developed for characterization and quality control of a number of the non-metallic materials used in military aircraft. These techniques have been largely limited to advanced composite prepregs and adhesives used in primary structure.

The objective of this program has been to evaluate the use of these techniques to improve the quality control of other non-metallic materials: in particular, the "consumable" materials used in the bonding and production of composites, and also the quality control of foaming adhesives.

These objectives were met. We have demonstrated the use of gas chromatography, fourier transform infrared analysis, and mass spectrometry for the identification and quantitative determination of off-gas products obtained under cure cycle conditions for a number of the fabrics, films, tapes, silicone elastomers, bag sealants, and cork dams used in our composite production facility. Also, chemical, thermal, and rheological properties have been quantitatively determined for FM404 foaming adhesive.

2.0 PROGRAM PLAN AND APPROACH

The technical approach is given in the Program Plan, Figure 1. Two categories of non-metallic materials were chosen as candidates for development of improved quality control methods: (a) consumables (materials used on bonding and composite production facilities) and (b) foaming adhesives.

PHASE I - DEVELOP METHODS FOR CONSUMABLES

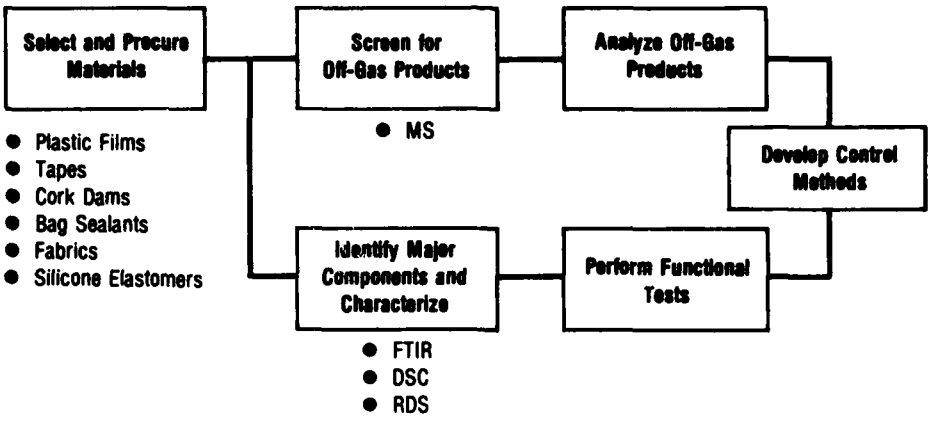
Sixteen consumable materials currently in use in our composite production facilities were chosen for test. Mass spectrometry was used to screen these materials for semi-quantitative amounts and to identify the off-gas products released under cure cycle conditions. Where off-gas products were present, standards were obtained and the amounts of the volatiles were determined by gas chromotography. Where applicable, the thermal and rheological properties were quantitatively determined for the consumables. Instrumental quality control methods were developed where a potential need was shown to exist.

PHASE II - ESTABLISH METHODS FOR FOAMING ADHESIVES

FM404 foaming adhesive was chosen for this investigation as being typical of this type of material. The chemical composition was determined. The components were separated, identified, and quantitatively measured. The expansion and outgassing characteristics were determined under simulated cure cycle conditions. Outgassing and foamed expansion were viewed in real time during cure by observing bubbles formed from specimens submerged in silicone oil.

The thermal characteristics of the foaming adhesive were established by thermogravimetric analysis (TGA) and by differential scanning calorimetry (DSC). The system rheology was defined using Rheometrics dynamic spectrometry (RDS). Viscosity profiles were generated as a function of time and temperature for varied cure cycle heating rates. Data from the thermal and rheological properties were correlated and related to the foaming character of the adhesive.

Phase I - Develop Methods for Consumables



Phase II - Establish Methods for Foaming Adhesives

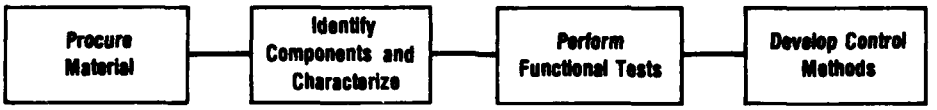


FIGURE 1
PROGRAM PLAN

3.0 TECHNICAL RESULTS

3.1 PHASE I - DEVELOP CONTROL METHODS FOR CONSUMABLES

Six categories of consumables were selected for testing and quality control improvement: fabrics, films, tapes, silicone elastomers, bag sealants, and cork dams.

First priority was given to determining the off-gassing characteristics under cure cycle conditions. The chemistry of the consumables and the amounts of volatiles produced must be known to evaluate their potential to affect the quality of the finished composite article.

Secondly, we determined the fourier transform infrared spectra to fingerprint these materials to obtain a better knowledge of their chemistry and to build a library of spectrograms for future reference. In addition, where applicable, thermal analysis and rheological test techniques were evaluated as methods for improving quality control.

3.1.1 Screening and Identification of Off-Gas Products - The volatiles were screened initially at 360°F using a chromalytic's 1047 sample concentrator interfaced with a DuPont 21-491 dual focusing gas chromotograph-mass spectrometer system. Where off-gas products were detected, preliminary identification was made using a computerized search system.

The materials tested and the analyses are listed in Table 1. Water is the most common off-gas product under these conditions; however, significant quantities of other off-gasses were detected in Schnee-Morehead 9151 bag sealant and Armstrong NC-710 cork dam materials.

3.1.2 Quantitative Analysis of Major Volatile Components - Seven of the materials were selected for further testing with a Varian gas chromatograph to determine the amounts of water present. The sample was placed in a small, heated glass tube which was interfaced with a chromalytics concentrator. A helium flow was directed over the sample, which was tested at 360°F. The moisture was trapped on a Porapak column and then backflushed into the chromatograph using the following conditions:

Column	-	Porapak Qs
Oven Temperature	-	120°C
Carrier Gas	-	Helium
Detector	-	Thermal Conductivity

The percent of moisture was determined from a standard working curve prepared by testing varied known amounts of water under the same conditions. The quantitative amounts of water found in the selected consumables are given in Table 2.

TABLE 1 - CONSUMABLE MATERIALS: DETECTION AND ANALYSIS OF OFF-GAS PRODUCTS BY MASS SPECTROMETRY

CONSUMABLE MATERIAL	PRODUCT	OFF-GASES
1. FABRICS		
- Release Cloth	CHR 9011	Some Water
	CHR 3TLL	None
- Peel Ply	Burlington 51789	Some Water
	Bleeder Lease A	Some Water
- Bleeder Cloth	Glass Style 120	None
	Glass Style 7581	None
- Breather Cloth	Airweave N-10	Some Water
	TM2206 (1000)	None
2. FILMS		
- Inner Bags	Tedlar E3760	Small Amount of Water, Small Amount of Oxygen Containing Compound
	FEP Teflon A4000	Some Water
- Vacuum Bags	Wrighton 7400 Green	Much Water
	Richman 8171 (Co-Ex)	Much Water
3. TAPES	3M855	Some Water
4. SILICONE ELASTOMERS	CHR 9455	Some Water; Small Amount of Low M.W. Alcohol
5. BAG SEALANTS	Schnee-Morehead 9151	Some Water, Small Amount of Carbon Disulfide (<0.007%), Small Amount of Perchloro-ethylene (<0.002%), Small Amount of Xylenes (<0.0047%), Some Alkenes of Varied Molecular Weight. Total Off-Gasses, Including Water = 1.1%
6. CORK DAMS	Armstrong NC-710	Much Water, Considerable Amounts of Unidentified Ethers, Alcohols, Aldehydes and Aromatic Compounds. Total Off-Gases Including Water = 3.8%

TABLE 2 - CONSUMABLE MATERIALS: WATER CONTENT

CONSUMABLE MATERIAL	PRODUCT	WATER (wt/wt %)
1. VACUUM BAGS	Wrighton 7400 Green Richman 8171 (Co-Ex)	2.0 2.1
2. TAPES	3M855	1.4
3. SILICONE ELASTOMERS	CHR 9455	0.15
4. CORK DAMS	Armstrong NC-710	0.77
5. BAG SEALANTS	Schnee-Morehead 9151	0.28
6. BREATHER CLOTH	Airweave N-10	0.23

A similar gas chromatographic technique was used to determine the percentage by weight of some of the other volatile materials found in the Schnee-Morehead 9151 bag sealant. These results are given in Table 1. However, the NC-710 cork dam off-gas products could be identified only by their general organic class. Without definite identification of the compounds, standards could not be prepared for quantitative analysis.

In a parallel in-house program, a black substance was found to be periodically clogging the vacuum lines of the autoclaves.

The substance was examined by FTIR and found to be a caprolactam, a precursor of Nylon 6. Hexane extraction of the Wrighton 7400 indicated the presence of a similar component. The caprolactam indicates that considerable Nylon 6 may be used in the vacuum bags purchased under the requirement that they contain only Nylon 66. Differential scanning calorimetry (DSC) was used to determine that the bags melt near the 205-210°C melting point of Nylon 6 rather than the 250°C melting point for Nylon 66.

Quality controls are being considered based on FTIR examination and DSC melting point determinations. The suppliers have been alerted to the problem and their assistance requested.

The Schnee-Morehead 9151 bag sealant was tested by DSC at three different heating rates and found to be thermally stable well beyond the cure temperatures required for epoxy prepregs and adhesives. Likewise, the rheology of the bag sealant was found to be functionally satisfactory.

The Rheometric dynamic spectrometer (RDS) was used to measure apparent viscosity under cure cycle conditions. Heating at 5°F/min to 360°F was followed by a hold at 360°F for 75 minutes. The starting viscosity was approximately 6×10^4 poise and dropped to a minimum near 6.5×10^3 poise at the hold temperature. During the 75 minutes hold, the viscosity slowly recovered to 2.2×10^4 poise.

Catalogue of Infrared Spectrograms - A Nicolet Model 7199 fourier transform infrared (FTIR) instrument was used to characterize the non-metallic consumables listed in Table 1. The spectrograms were catalogued and filed for future reference. The FTIR fingerprints can be used as a rapid cross-check for any suspected change in the chemistry of the non-metallic consumables. A copy of the files containing the full-sized spectrograms will be made available to NAVAIR and its designees upon request. Reduced copies of the spectrogram are given in the Appendix.

3.2 PHASE II - DEVELOP CONTROL TEST METHODS FOR FM404 FOAMING ADHESIVE

The quantitative analysis of FM404 foaming adhesive is given in Table 3. The schematic for resin separation and component identification is given in Figure 2.

The acetone soluable portion was examined using the DuPont 21-491B gas chromotograph-mass spectrometer. Two components were detected and were shown to be an epoxy phenol novolac (EPN) and a second epoxy, diglycidyl ether of bisphenol A(DGEBA).

The quantitative amount of DGEBA was determined using a 5730A Hewlett-Packard gas chromatograph employing the following conditions.

Column	- Dexsil 300 (8 ft., stainless steel)
Oven Temperature	- 200°C initial, programmed to 350°C @ 8°C/min
Injection Port	- 300°C
Detector	- Flame Ionization @ 350°C
Carrier Gas	- Helium

The major peaks, with their exact elution times, are shown in Figure 3. Weighed samples of DGEBA were dissolved in acetone and a standard working curve was prepared in acetone for use in determining the amount of the minor epoxide. The major epoxy (EPN) was determined by difference. The curing agent, dicyandiamide (DICY) was identified from an infrared (IR) spectrogram. An IR spectrogram of a synthetic mixture of EPN and DICY gave a very good match with that of the acetone solubles from FM404, thus confirming the presence of these two components in the adhesive.

The acetone insolubles were weighed, and a portion examined by emission spectroscopy (ES) was found to contain aluminum and silicon. The aluminum was present as a metal powder and was readily separated from the remaining acetone insolubles by leaching with hydrochloric acid. The remaining insolubles were weighed and examined by atomic absorption (AA) and shown to contain silicon and magnesium. Further analysis, using the Nicolet 7199 Fourier transform infrared (FTIR) instrument, showed that the elements of silicon and magnesium, detected by AA, were present in the form of the compounds, Cab-O-Sil (silicon diaxide) and asbestos (a magnesium silicate mineral). These two components are commonly used in a fine powder form as flow control agents. The Cab-O-Sil is often premixed with the DICY curing agent to aid in obtaining a homogeneous dispersion of the DICY.

The blowing agent in FM404 appeared to be insoluble in acetone and remained in the filter cake with the aluminum powder and the fillers. The filtrate, which contained the two epoxies and DICY, cured without any foaming. Attempts to separate the exact blowing agent and identify it were not successful. It is assumed that, as in typical foaming adhesive formulations, the blowing agent is present in the range of 1-3%.

TABLE 3 - IDENTIFICATION AND ANALYSIS OF FM404 FOAMING ADHESIVE

COMPONENT	FUNCTION	QUANTITATIVE ANALYSIS (WT %)
Epoxy Phenol Novolac	Major Epoxide	70 - 73
Diglycidyl Ether of Bisphenol A	Minor Epoxide	4.5 - 5.0
Dicyandiamide (DICY)	Curing Agent	5.4
Aluminum Powder	Toughner	16.0
Asbestos + (Cab-O-Sil)	Flow Control	1.0
---	Blowing Agent	(1-3)

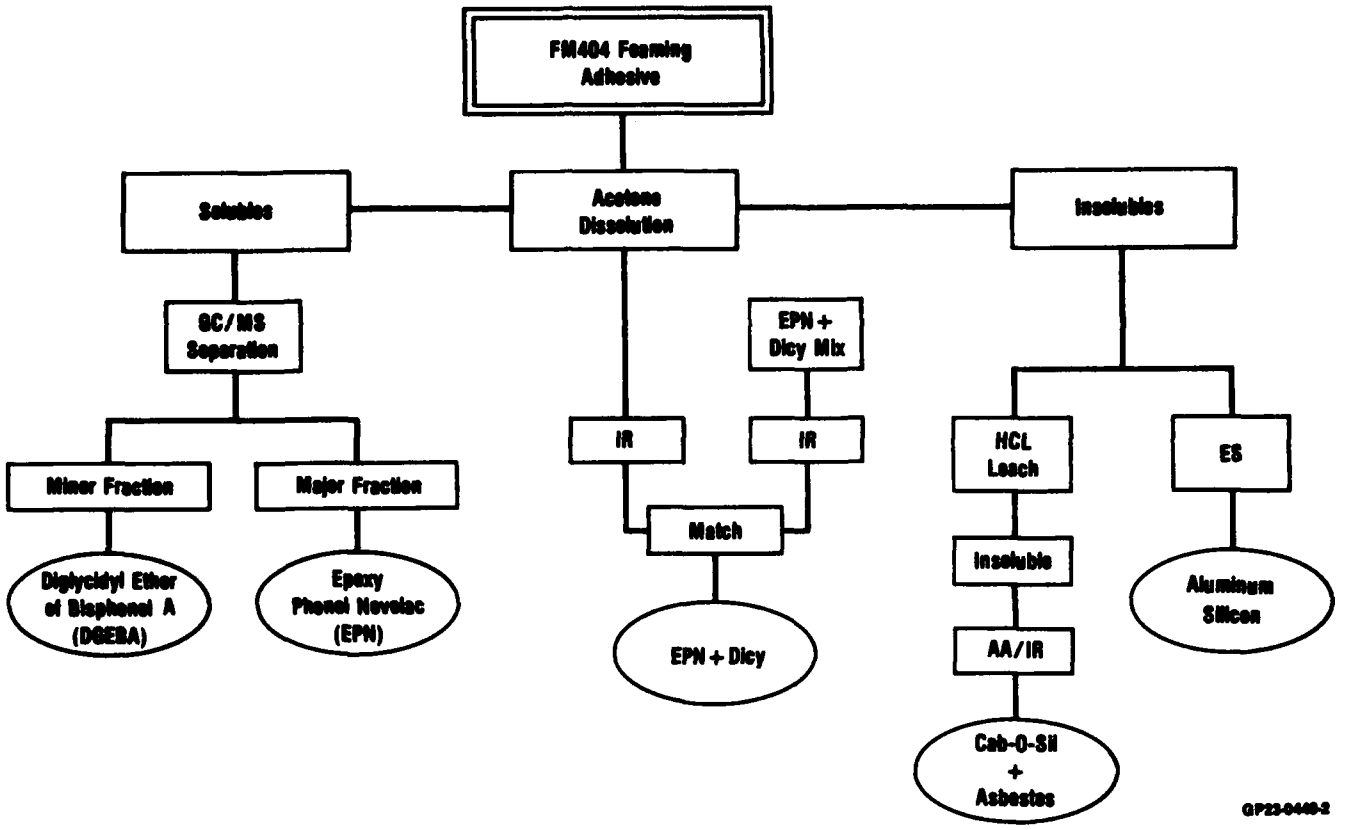


FIGURE 2
SEPARATION AND IDENTIFICATION OF FM404 ADHESIVE

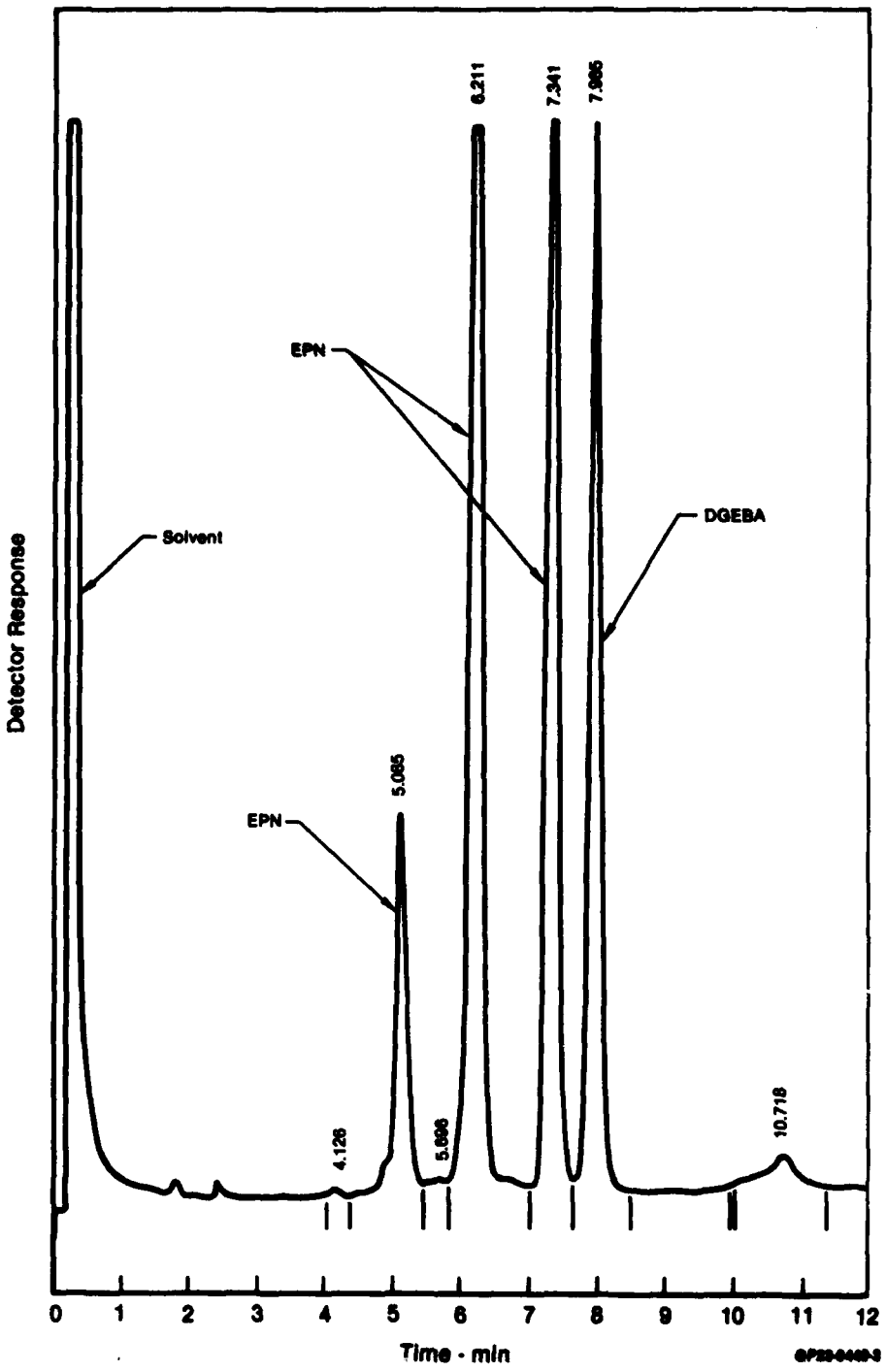


FIGURE 3
GAS CHROMATOGRAM OF ACETONE - SOLUBLE FRACTION OF FM404 ADHESIVE

Expansion and Out-Gassing of FM404 Viewed in Real Time - Expansion and volatiles release for the foaming adhesive were observed under simulated cure cycle conditions. Beakers containing FM404 specimens submerged in clear, colorless silicone oil were placed in a vacuum oven having a large view port. The oven was programmed to heat at 2°C/minute and hold at 180°C (360°F) under a vacuum of about 29 in.

The expansion and quantity of bubble formation in the silicone oil could be observed throughout the cure cycle. Bubbles started at room temperature and increased with increasing temperature. Copious bubbling indicated a greater release of volatiles than expected. A burst of vigorous bubbling took place at about 135°C (275°F), indicating the reaction release of inert gas by the blowing agent (later confirmed by thermal and rheological characterization). Escape of large amounts of blowing agent gas indicates that much of the gas is not trapped by closed cell foam.

Thermal Characteristics of FM404 - Thermogravimetric analysis (TGA), presented in Figure 4, shows the percentage of weight loss as a function of temperature for a linear heating rate of 2.5°C/minute. In the normal temperature range of the cure reaction, weight loss is shown to be 0.44%. At higher temperatures, two distinct degradation reactions are detected; the first resulting in a weight loss of 0.82% and the second in a loss of 1.2%. Differential scanning calorimetry (DSC) runs were then made at three different linear heating rates. DSC thermograms for heating rates of 1.25, 2.5, and 5.0°C are shown in Figure 5-7. Preliminary examination of the curves shows that a vigorous exotherm takes place over a relatively narrow temperature range. This is typical for DICY cured epoxy systems since the DICY is present as a fine insoluble powder until it starts to dissolve in the epoxy at elevated temperatures. Once DICY begins to dissolve, a rapid exothermal reaction follows.

Allowed out-time for systems in which DICY is the only curing agent are dependent on the relative humidity, since moisture dissolves some of the DICY at room temperature. The moisture-solubilized DICY allows the cure reaction to start at a lower temperature, which in the case of FM404 could interfere with the blowing agent reaction. For example, moisture can cause premature gel and stop the foaming action before full expansion is reached.

In a separate in-house study, it was found that four to six layers of the FM404 film generated heat much faster than it could be transported away and temperatures of 750-800°F were reached, with as much as 34% weight loss. Table 4 shows the decrease in weight with the increase in the number of plies. This large amount of gaseous degradation products can be the cause of "blown core" in aluminum

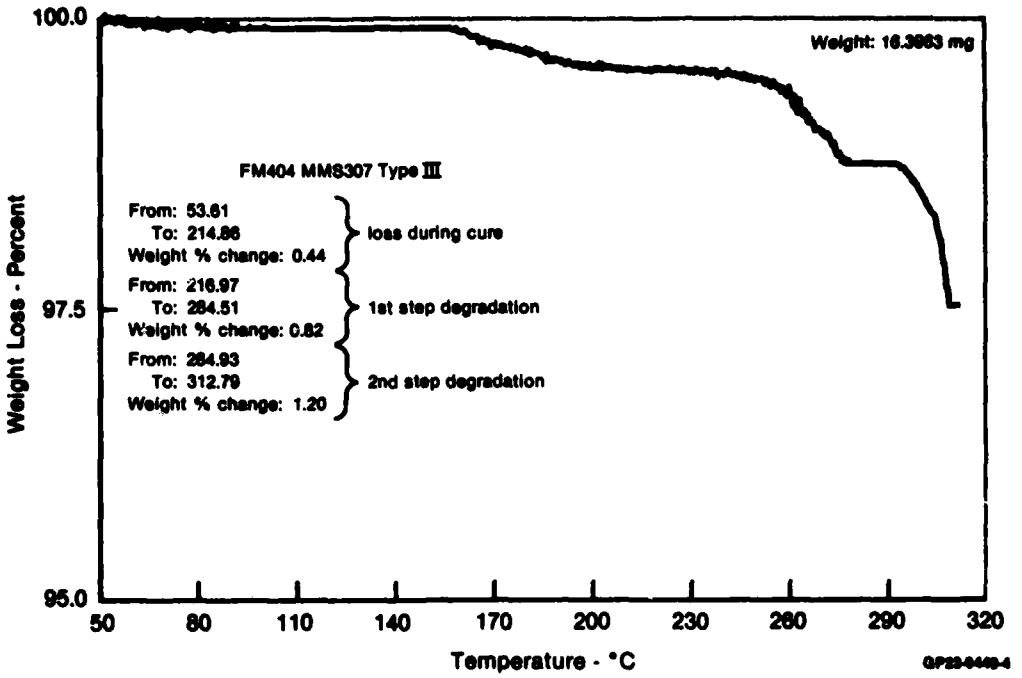


FIGURE 4
THERMOGRAVIMETRIC ANALYSIS OF FM404 FOAMING ADHESIVE AT 2.50°C/MIN HEATING RATE

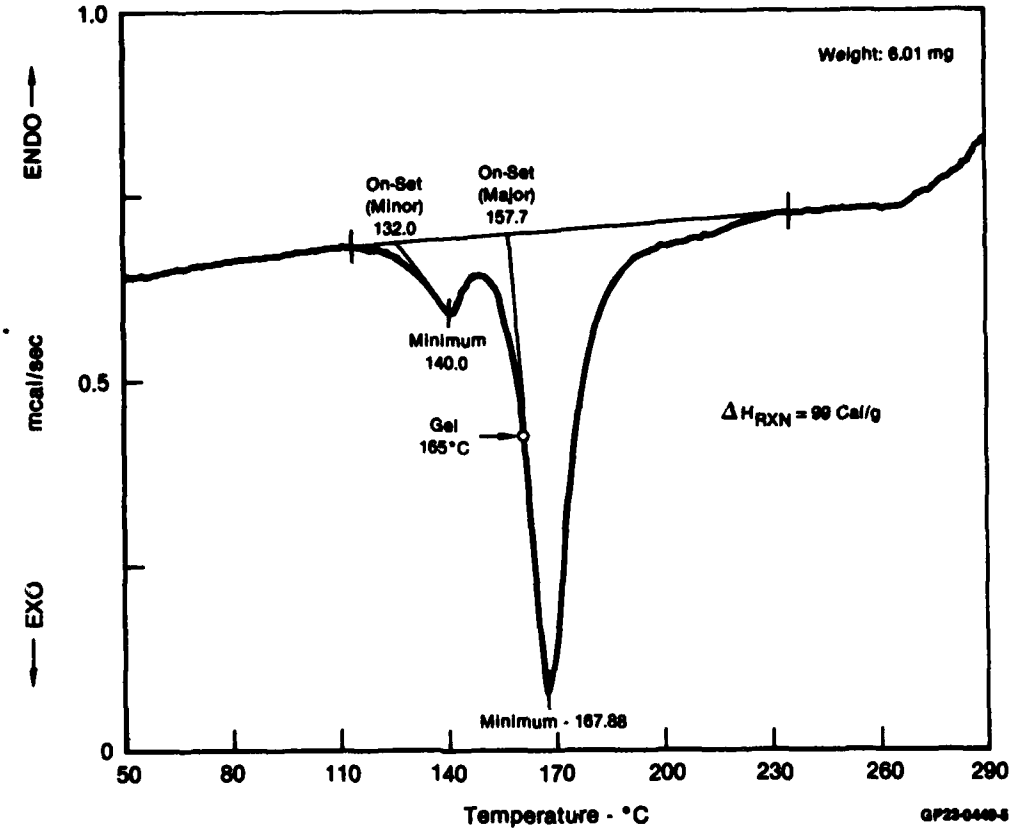


FIGURE 5
DSC THERMOGRAM OF FM404 FOAMING ADHESIVE AT 1.25°C/MIN HEATING RATE

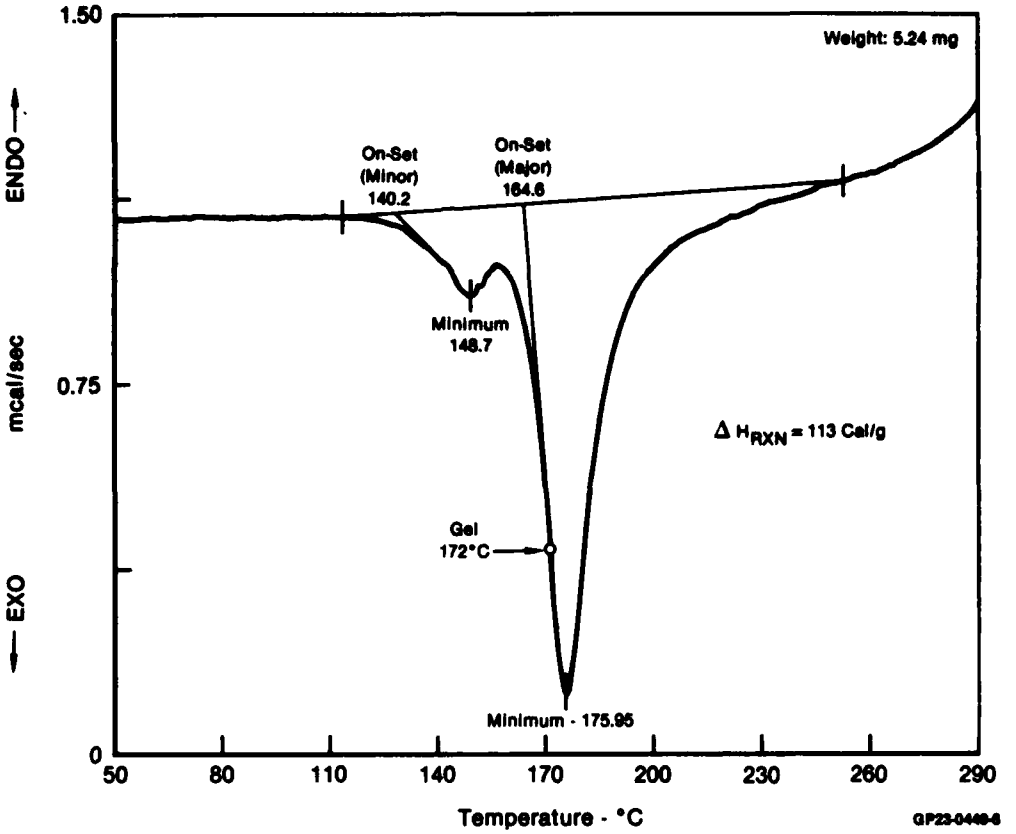


FIGURE 6
DSC THERMOGRAM OF FM404 FOAMING ADHESIVE
AT 2.50°C/MIN HEATING RATE

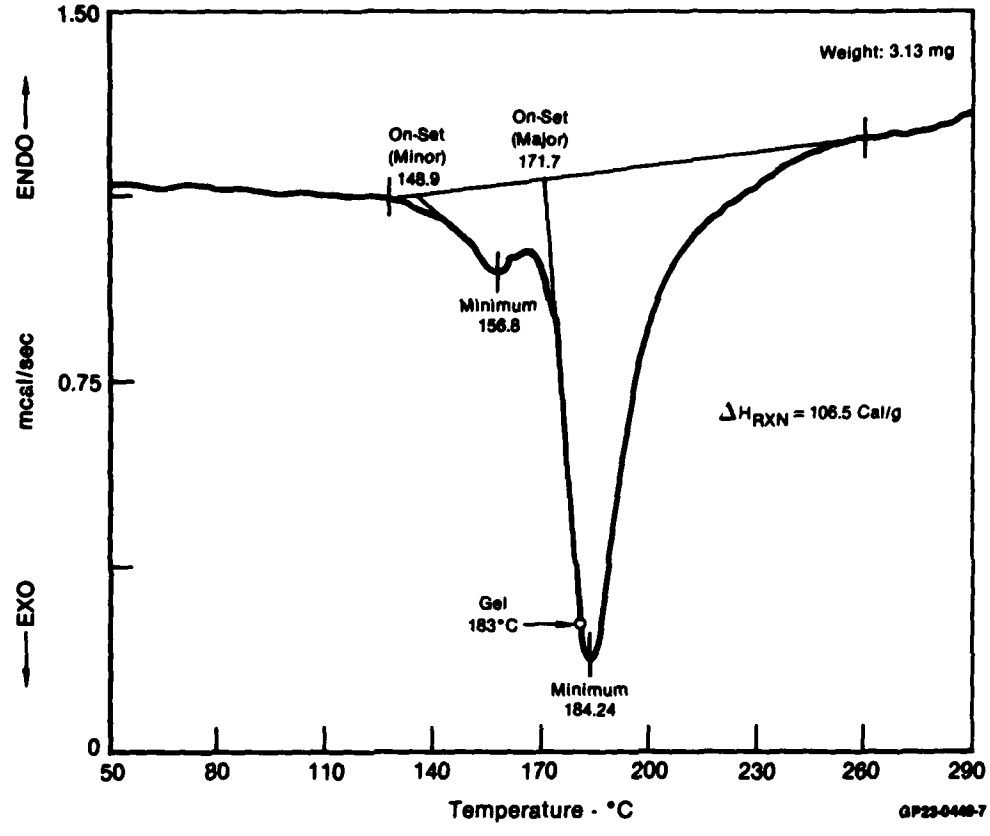


FIGURE 7
DSC THERMOGRAM OF FM404 FOAMING ADHESIVE AT 5°C/MIN HEATING RATE

TABLE 4

MASS LOSS OF FOAMING ADHESIVE

WITH VARIED PLY THICKNESS

	FINAL MASS (GRAMS)	INITIAL MASS (GRAMS)	MASS LOSS %
1 ply	2·3425	2·3566	·63
1 ply	2·5365	2·5526	·63
2 ply	4·7429	4·8684	2·58
2 ply	4·4559	4·4979	0·93
2 ply	4·6790	4·7468	1·43
3 ply	7·1021	7·8014	8·96
3 ply	6·3029	7·1428	11·7
4 ply	7·3717	10·1786	27·6
6 ply	9·8242	14·8610	33·9

honeycomb, adjacent to the bondline. For this reason, core-to-core and core-to-sheet bonding with FM404 is limited to the use of a maximum of two plies of the foaming adhesive.

The preliminary minor exotherm peaks shown in the thermograms for FM404 are not found in non-foaming DICY cured epoxies such as FM400 adhesive and BR 400 primer. It appears, therefore, that the preliminary minor exotherm is due to a reaction involving the blowing agent. It was subsequently shown, from viscosity profiles taken at varied linear heating rates, that the minor exotherm occurs at temperatures between low viscosity and gel.

The areas under the exotherm were used to calculate the heat of reaction. The three values obtained give an average of 106 cal/g.

For the three DSC thermograms, Figure 5-7, four critical temperatures were automatically measured for each of the different heating rates: (a) the onset (minor peak), (b) the exotherm (minor peak), (c) the onset (major peak) and (d) the exotherm (major peak).

Therefore T_1 is the temperature for the onset of the foaming reaction and T_2 represents the point of maximum rate for the foaming reaction. Likewise, T_3 and T_4 represent the same points for the epoxy-DICY cure reaction. Any of the sets of critical temperature points determined for a series of DSC runs can be related to the heating rates by the following expression:

$$\log \phi = A/T + B$$

where:

ϕ = Heating rate (°c/min)

T = Temperature (°K)

A = Constant, related to activation energy

B = Constant, related to the arrhenius frequency factor

A and B can be determined from the DSC data from the best straight through a plot of log ϕ vs 1/T.

Table 5 lists the temperatures at 3 different heating rates for each of the critical points. Also given is Equation (1), showing the values of the constants A and B as calculated by linear regression of log ϕ vs 1/T for each of the four critical points. The exceptionally high values for correlation coefficient (r^2) indicate excellent statistical fits for the data. Thus, using these equations, we can calculate the critical points for any selected heating rate. Samples will be set aside from the next five batches of FM404 and will be tested in replicate to determine suitable quality control limits based on the critical points.

TABLE 5 - DSC DATA FOR FM404 FOAMING ADHESIVE AT FOUR CRITICAL TEMPERATURES

CRITICAL POINT	HEATING RATE, ϕ, (°C/MIN)	TEMPERATURE T(°C)	EQUATION RELATING ϕ(°C/MIN) AND T(°K)
On-Set (Minor Peak)	1.25	132.0	$\log \phi = -\frac{6087}{T} + 15.1275$
	2.50	140.2	
	5.00	148.9	$r^2 = 0.99997$ (statiscal fit)
Exotherm (Minor Peak)	1.25	139.9	$\log \phi = -\frac{6314}{T} + 15.3834$
	2.50	148.7	
	5.00	156.8	$r^2 = 0.9988$
On-Set (Major Peak)	1.25	157.7	$\log \phi = -\frac{8237}{T} + 19.2207$
	2.50	164.6	
	5.00	171.7	$r^2 = 1.00000$
Exotherm (Major Peak)	1.25	167.9	$\log \phi = -\frac{7445}{T} + 16.9821$
	2.50	176.0	
	5.00	184.2	$r^2 = 0.9995$

Rheological Characteristics of FM404 - Rheology determinations were made using the Rheometrics dynamic spectrometer, RDS Model 7700.

It is a dynamic, oscillatory rheometer capable of measuring rheology over a wide range of temperatures and can be programmed for any combination of linear heating rates, isothermal holds, and simulated cure cycle conditions. It provides continuous printout of data and automatically plots dynamic viscosity (η), loss modulus (G") and storage modulus (G'). In addition, in the plate-to-plate mode, measurements can be made on the as-received film adhesive. The RDS instrument settings used were:

Plate Diam	- 25 mm
Plate-to-Plate (Gap)	- 1.0 mm
Initial Temperature	- 50°C
Strain	- 20%
Frequency	- 10 rad/sec

The Rheograms in Figure 8 show the effect of different heating rates on the apparent viscosity as a function of time. These viscosity profiles were determined for three heating rates: 1.00, 2.35, and 2.90. The data for the gel point is given in Table 6. The engineering gel point is considered to be the point where the viscosity reaches 1000 poise (10^5 CPS) and flow has effectively stopped.

The equation relating heating rate (ϕ) and gel temperature (T_{gel}), shown in Table 6, was calculated from RDS experimental data. This equation was used to calculate T_{gel} for the heating rates of 1.25, 2.5, and 5.0°C/min for direct comparison with the DSC data. The T_{gel} values for all heating rates fall between the DSC onset (major peak) and the major exotherm peak. The gel points are plotted on the DSC thermograms shown in Figure 5-7.

The DSC equations relating heating rate and the critical point temperatures given in Table 5 were transposed to the heating rates used for the RDS rheograms. The DSC critical points are plotted on the viscosity profiles shown in Figure 8. An unexplained rise in the apparent viscosity peaks out at the DSC onset (minor peak) for all three of the RDS heating rates. The DSC onset (major peak) occurs just prior to the rapid rise in viscosity as the system moves toward gel. Thus, we have demonstrated that the thermal and rheological data are consistent, interrelated and this provides a means for improved quality control testing for the foaming adhesive.

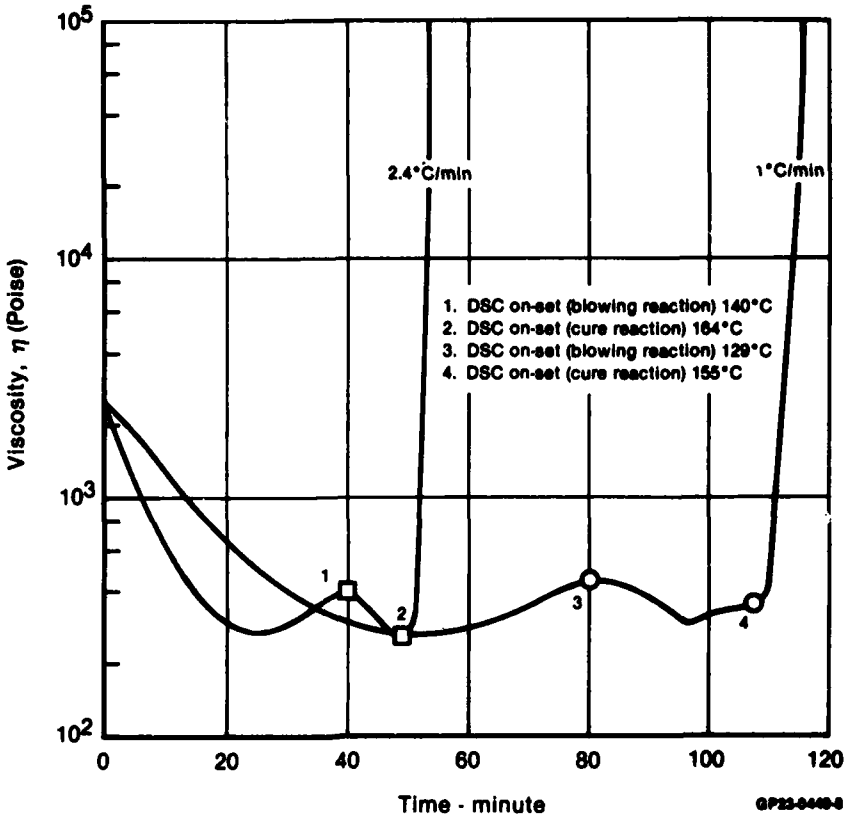


FIGURE 8
EFFECT OF HEATING RATE ON VISCOSITY PROFILE OF FM404 FOAMING ADHESIVE

TABLE 6

RHEOLOGICAL (RDS) DATA FOR FM404 FOAMING ADHESIVE

CRITICAL POINT	HEATING RATE, ϕ, (°C/MIN)	TEMPERATURE (°C)	EQUATION RELATING ϕ AND T_{gel}
GEL (T_{gel}) (Experimental)	1.00	158.0	$\log \phi = -\frac{5465}{T(°K)} + 12,6787$
	2.35	171.5	$r^2 = 0.998$
	2.90	174.0	
GEL (T_{gel}) (Calculated from equation)	1.25	161.4	
	2.50	172.0	
	5.00	183.2	

4.0 CONCLUSIONS

A file of FTIR spectra was created for the major non-metallic consumable materials used in the bonding and composites fabrication facility. It will serve as a source of primary reference in detecting suspected changes in the chemistry of vendor products.

The nylon vacuum bags, Armstrong NC-710 cork dam material, and Schnee-Morehead 9151 bag sealants, consumables showed the largest amount of total off-gas products under the time/temperature parameters of cure.

With the exception of water content, quality control of the very complex mixture of off-gas products is limited to batch-to-batch comparison by mass spectrometry.

Water is the most common volatile encountered. Of the six consumables quantitatively tested for water content, the nylon vacuum bags showed the greatest amounts, at a level of 2%. Gas chromatography was found to be the best method for quality control.

For the foaming adhesive, RDS viscosity measurements made at varied heating rates can be correlated with the DSC thermal reaction data for the same heating rates. The DSC onset for the DICY cure reaction takes place just ahead of the RDS-measured resin gel point. The combination of RDS and DSC testing provides the basis for quality control testing to assure proper foaming action for FM404.

The foaming adhesive is shown by DSC to have an exothermal "spike cure"; i.e., a relatively large amount of heat is released within a narrow temperature range. The use of multiple plies must be avoided to prevent a local overheat situation that can result in blown cores in adjacent honeycomb core materials.

Excess moisture in FM404 leads to an early onset of cure, with premature gel which can interfere with the foaming reaction and have an adverse effect on the adhesive performance. DSC tests are required on specimens having various moisture levels, to determine an acceptance limit for quality control.

APPENDIX A

FOURIER TRANSFORM INFRARED SPECTRA FOR CONSUMABLE MATERIALS USED IN THE BONDING AND COMPOSITES FABRICATION FACILITY

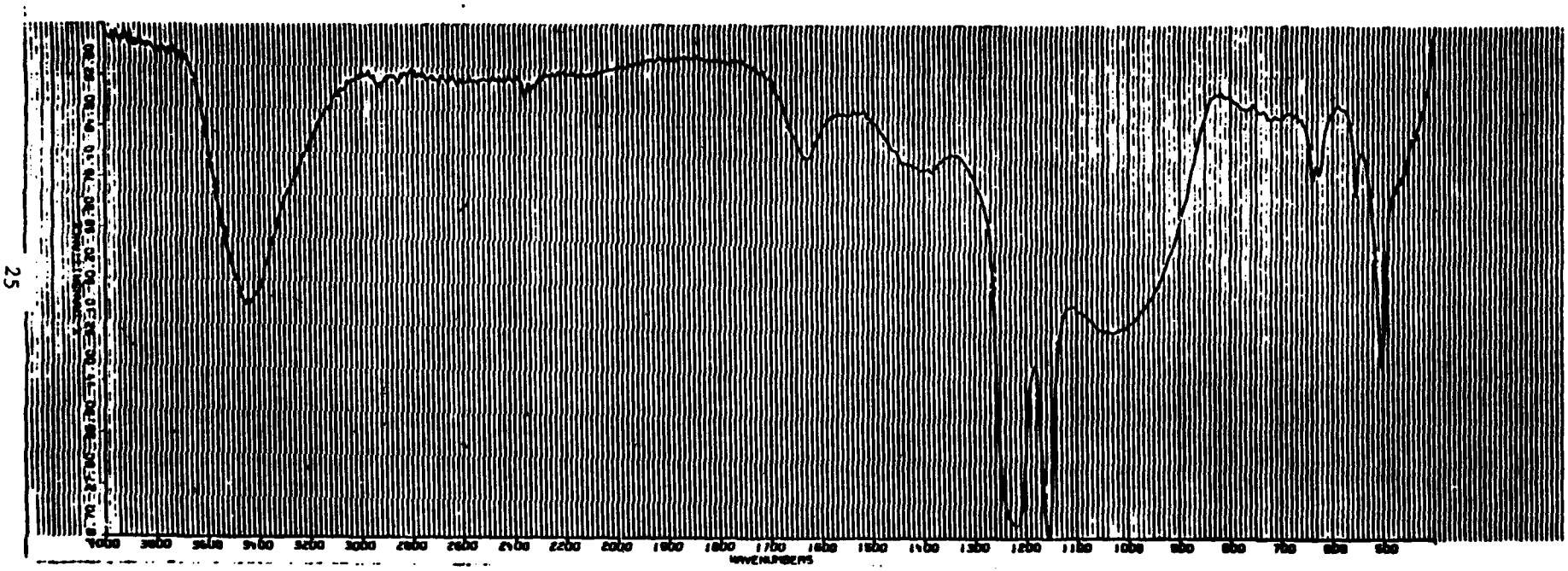


Figure A-1 - Release Cloth, CHR 9011

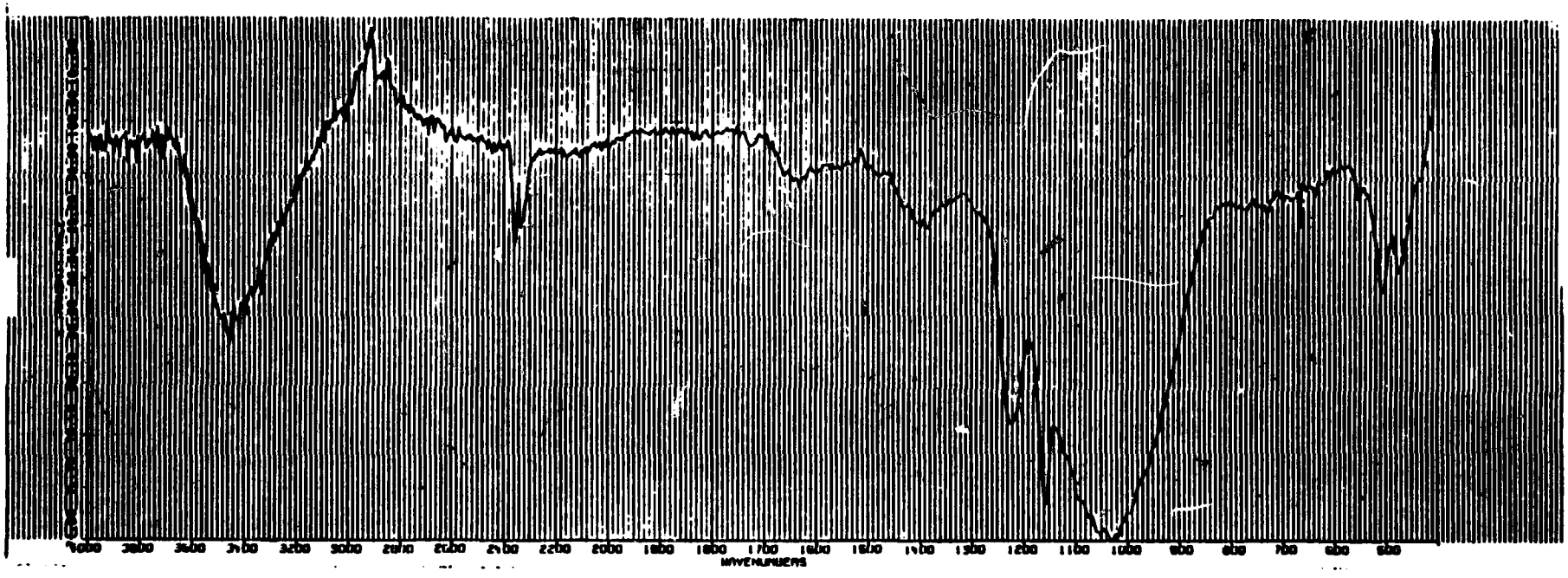


Figure A-2 - Release Cloth, CHR 3TLL

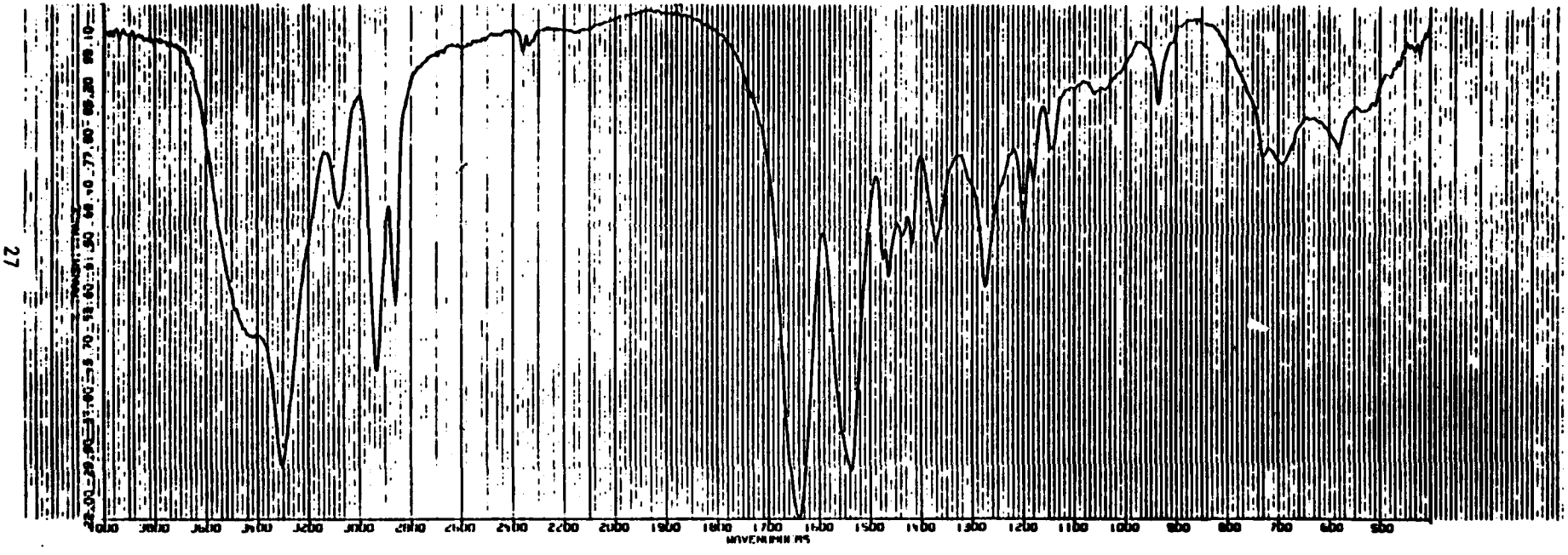


Figure A-3 - Peel Ply, Burlington 51789

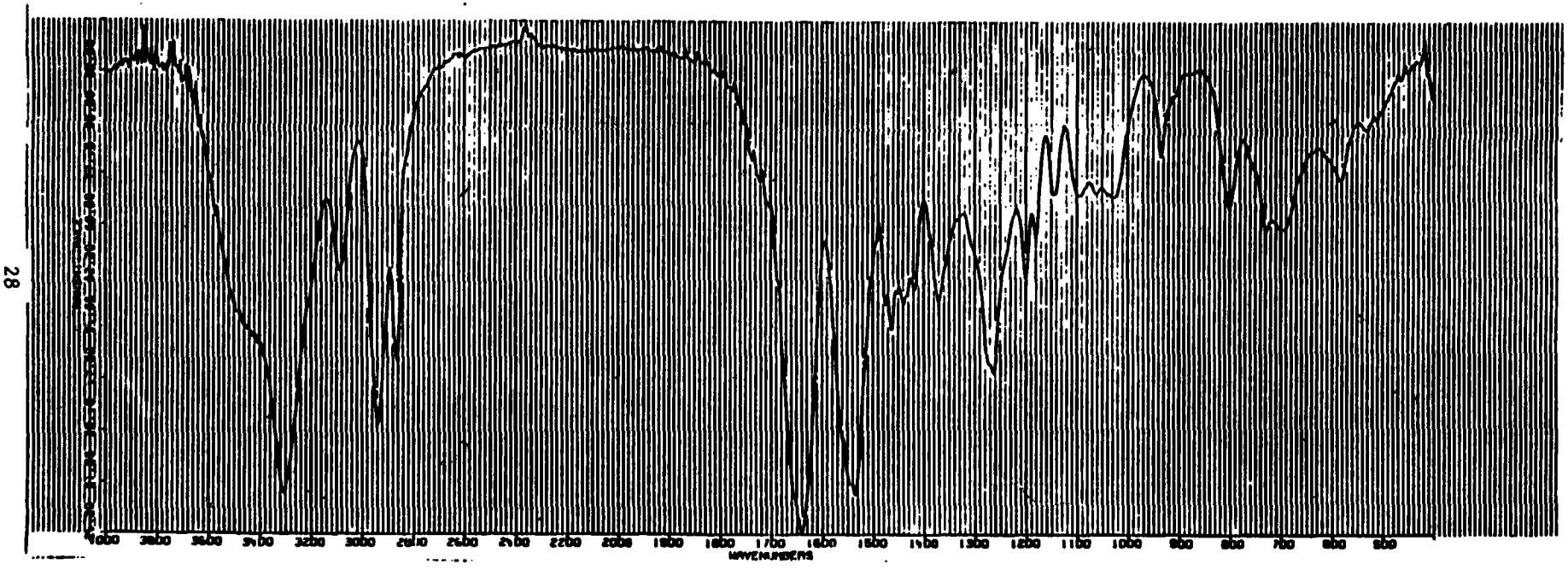


Figure A-4 - Peel Ply, Bleeder Lease A

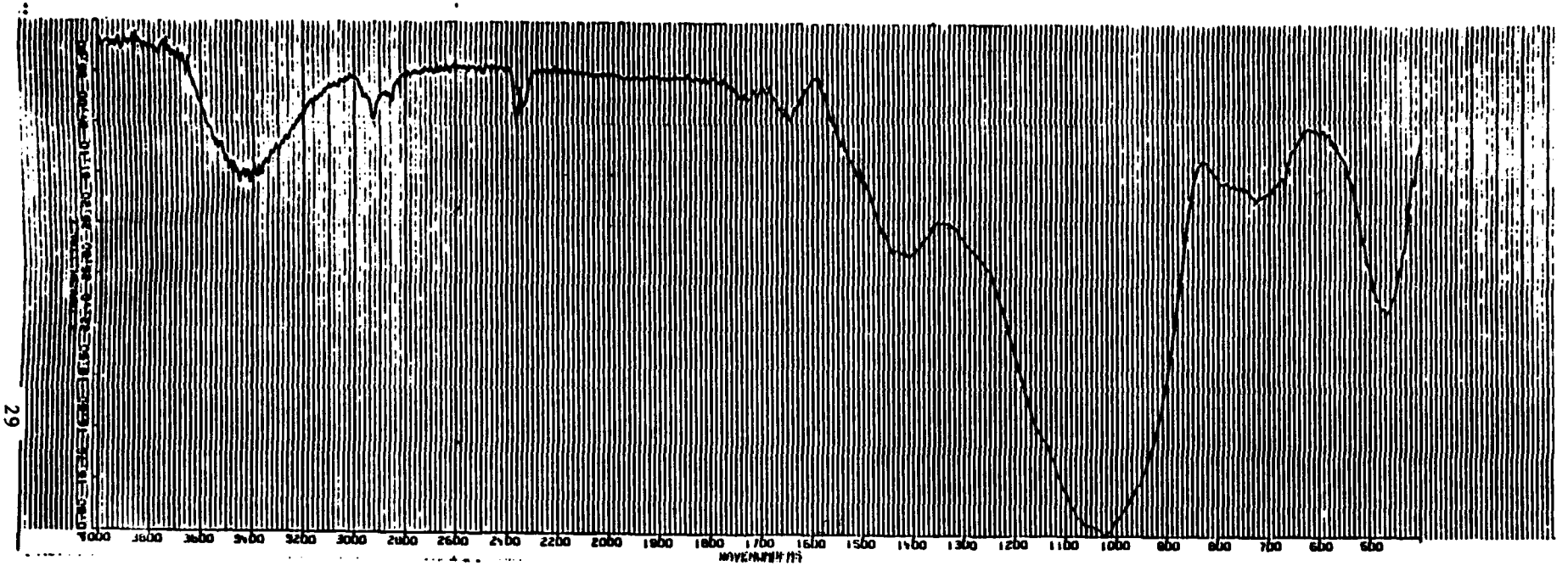


Figure A-5 - Bleeder Cloth, Glass Style 120

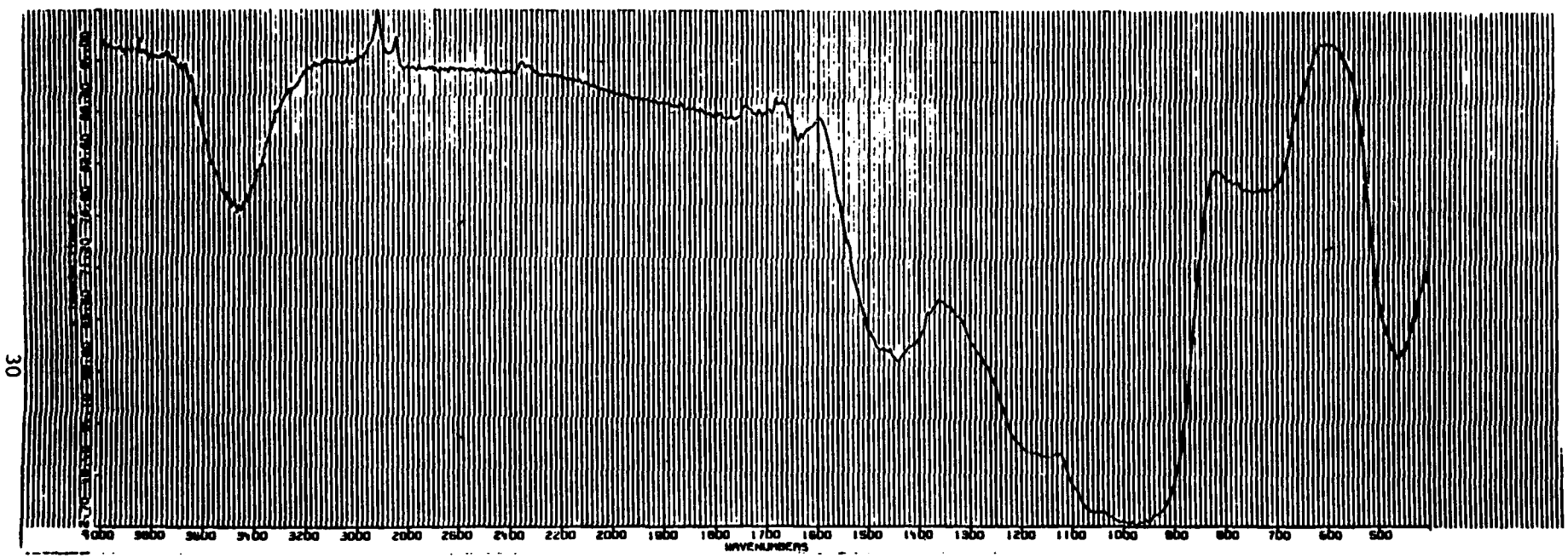


Figure A-6 - Bleeder Cloth, Glass Style 7581

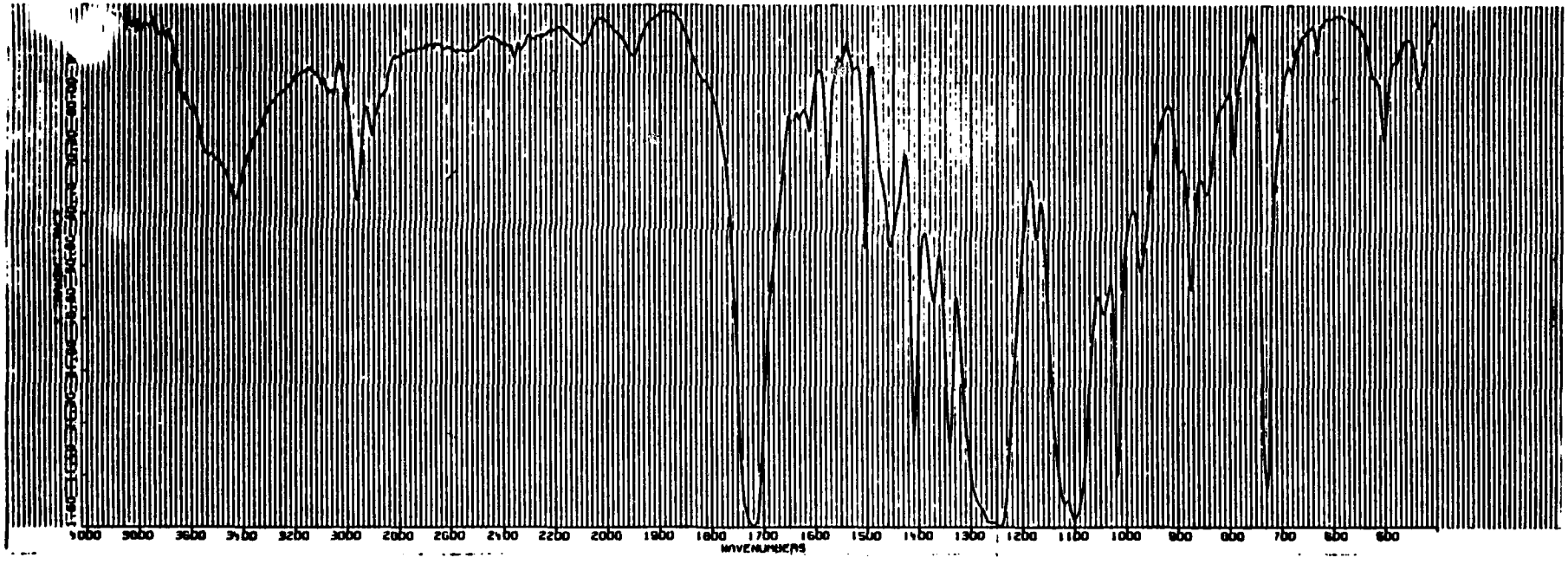


Figure A-7 - Breather Cloth, Airweave N-10

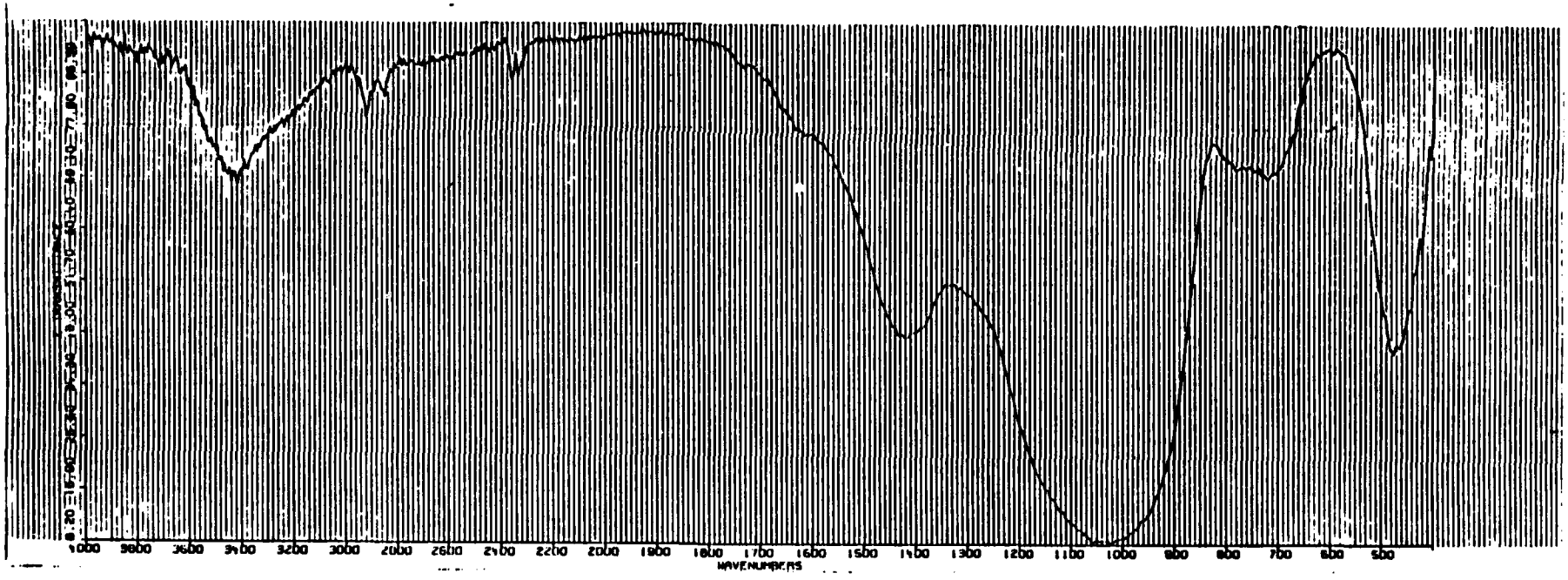


Figure A-8 - Breather Cloth, TM2206 (1000)

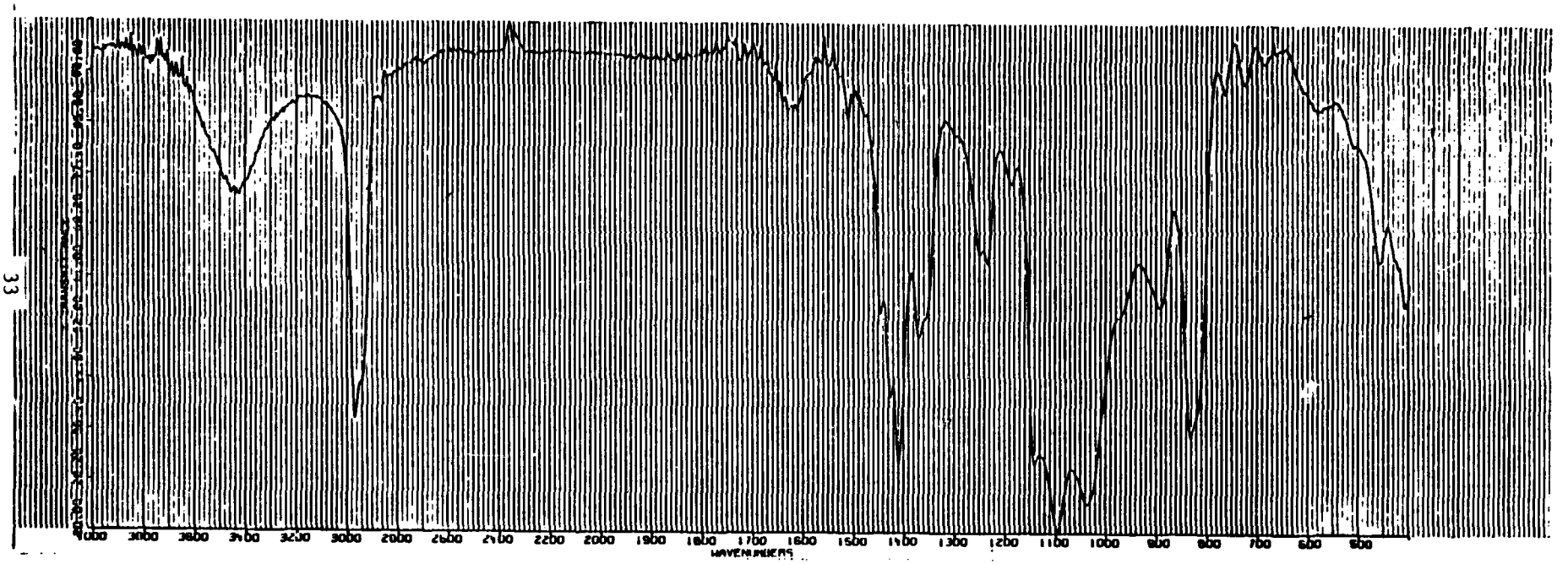


Figure A-9 - Inner Bag, Tedlar E3760

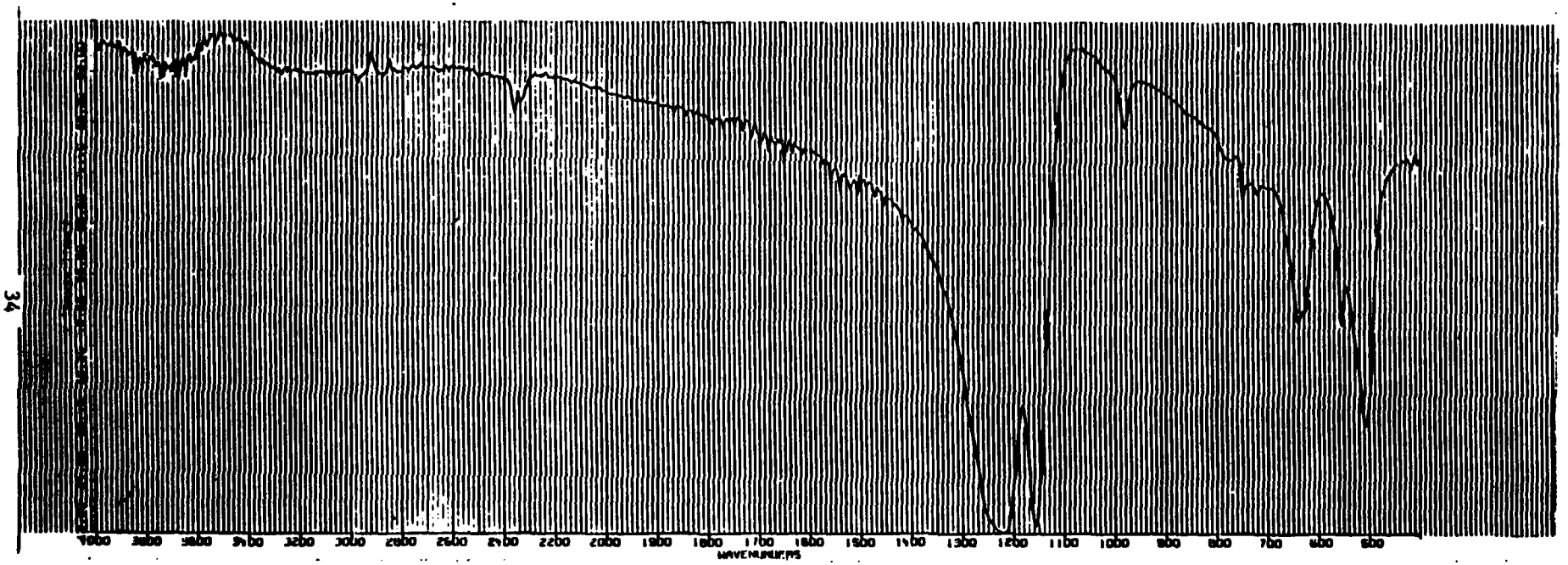


Figure A-10 - Inner Bag, FEP Teflon A4000

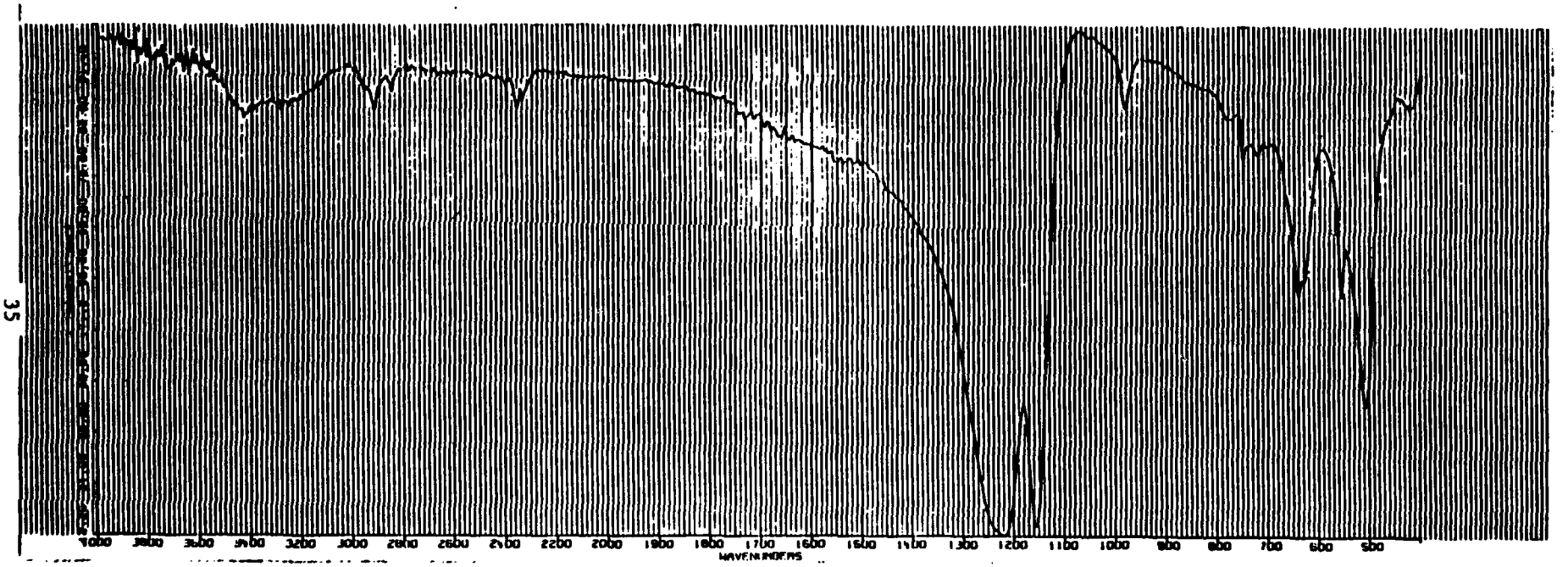


Figure A-11 - Vacuum Bag, Wrighton 7400 Green

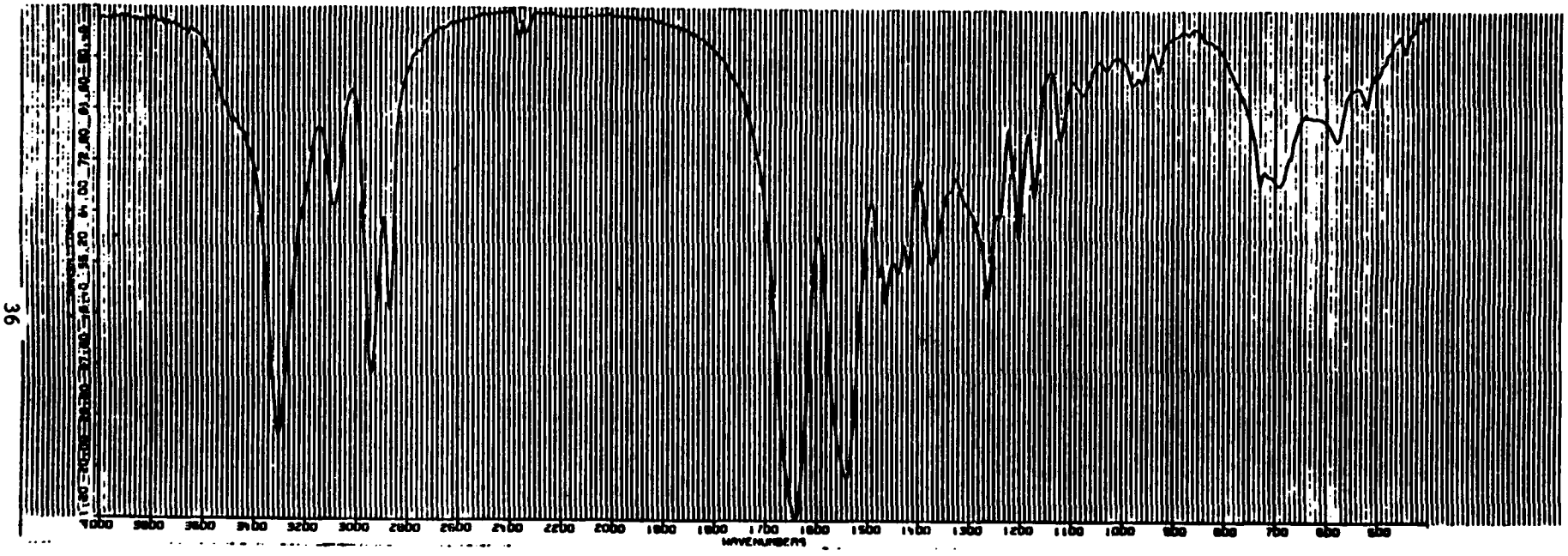


Figure A-12 - Vacuum Bag, Richman 8171 (Co-Ex)

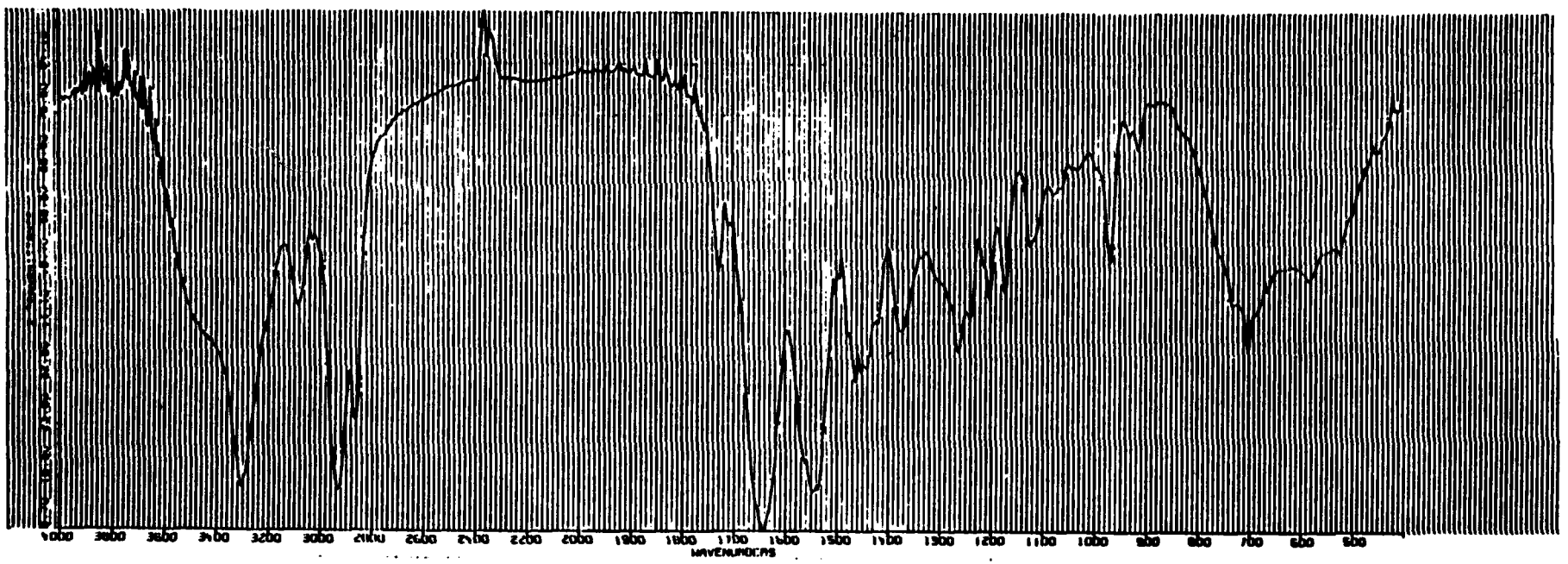


Figure A-13 - Tape, 3M855

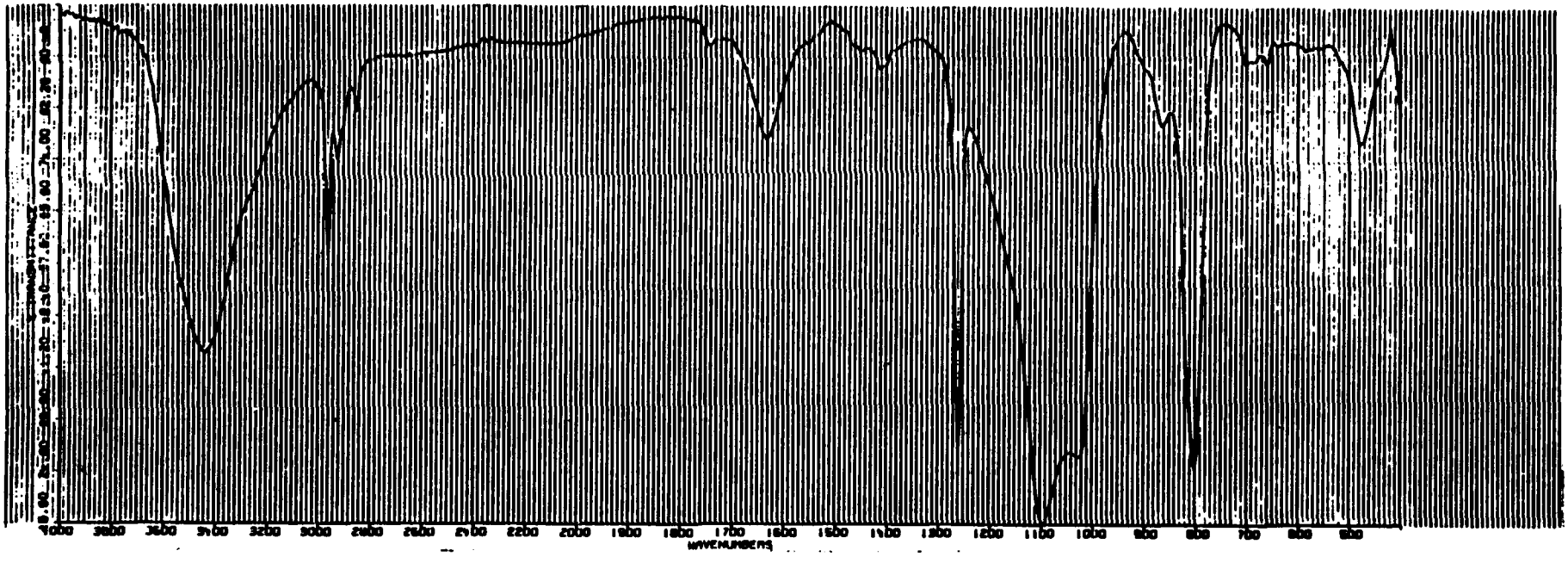


Figure A-14 - Silicone Elastomer, CHR 9455

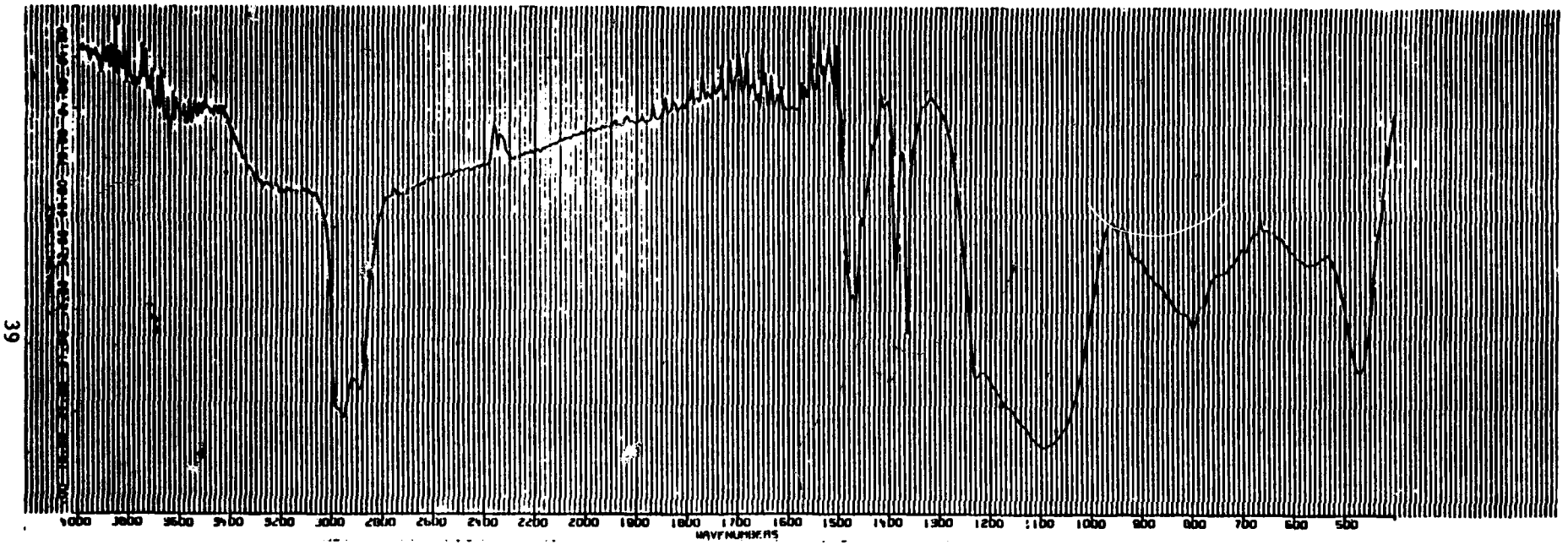


Figure A-15 - Bag Sealant, Schnee-Morehead 9151

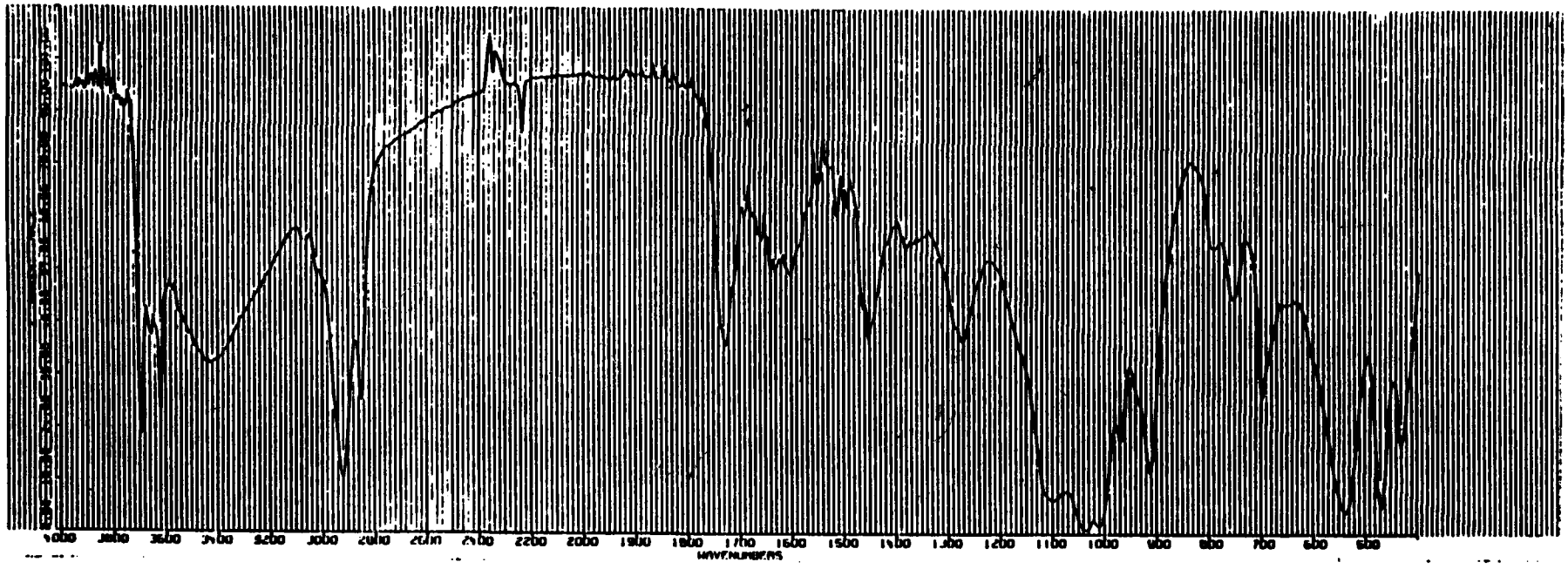


Figure A-16 - Cork Dam, Armstrong NC-710

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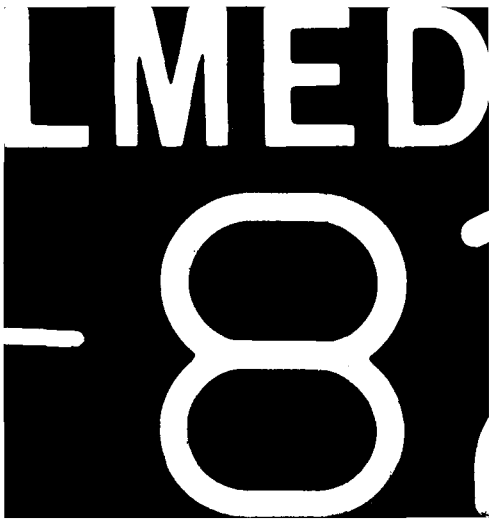
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